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On Twinkling. By M. Arago.*

M. Arago commences his inquiry by giving an exact definition of the term *scintillation.* It is, he remarks, from not adopting a similar practice that astronomers and other physical inquirers have hitherto failed to arrive at a satisfactory explanation of the phenomenon. He affirms, then, that, in so far as naked-eye observers of the heavens are concerned, scintillation or twinkling consists in very rapid fluctuations in the brightness of the stars. These changes are almost always accompanied by variations of colour and certain secondary effects, which are the immediate consequences of every increase or diminution of brightness; such as considerable alterations in the apparent magnitudes of the stars, and in the length of the diverging rays, which appear to issue in different directions from their centres.

It has been remarked from a very early age that the phenomenon of twinkling is accompanied by a *change of colour.* M. Arago states, upon the authority of M. Babinet, that the name of *Barakesch*, given by the Arabians to the star *Sirius*, signifies *the star of a thousand colours.* He also cites various passages from the works of Tycho Brahé, Kepler, and other modern inquirers, indicative of a similar change of colour attending the process of twinkling.

M. Arago asserts further, that *the twinkling of the planets* is a well-established fact. Thus observers generally, from Tycho Brahé downwards, have remarked that *Mercury* twinkles very strongly. Gassendi even maintains that it is on account of this circumstance that the appellative Στιλϐων has been applied to the planet. *Venus* has also been observed to twinkle, and even *Mars* and *Jupiter*, though feebly. Tycho Brahé has remarked that *Saturn* never twinkles; but this opinion has been controverted by Scheiner and other observers, although it is generally admitted that the phenomenon is exceedingly difficult to be recognised in the case of this planet.

An impression has generally prevailed that the stars do not twinkle in telescopes. M. Arago, however, asserts that this opinion is erroneous. Even a few years after the invention of the telescope Simon Marius remarked that, by removing the eye-piece of the telescope, the images of the stars and planets appear enlarged, and exhibit rapid fluctuations of brightness and colour. In 1813, Nicholson showed that a similar phenomenon would be produced if the eye-piece of an achromatic telescope was pushed out of focus. The same inquirer also gave an account of another experiment, which tended to illustrate the rapid fluctuation of colour which the stars undergo during the process of twinkling. The telescope being adjusted to distinct vision, he applied to it a smart vibration, which caused the image of the star to be transformed into a curved line of light, returning into itself, and diversified by

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* *Annuaire du Bureau des Longitudes*, 1852, pp. 365–504.

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several colours. A similar phenomenon presented itself on the occasion of each successive vibration. He estimates that each colour occupied about a third of the whole length of the curve, and assuming that he applied ten vibrations to the telescope in the course of a second, he hence concluded that the light of *Sirius passes through thirty changes of colour in a second of time.*

It follows, as a necessary consequence of this experiment, that the stars in general shine only by a portion of their light, the effect of twinkling being to diminish their brightness. It is easy to conceive, therefore, that a star which is estimated to be of the seventh magnitude, because it is usually invisible to the naked eye, might become distinctly perceptible if the phenomenon of twinkling were to cease.

After giving a detailed account of the circumstances which accompany the twinkling of the celestial bodies, and of the modifications to which they are subject, M. Arago next proceeds to explain his views of the physical origin of the phenomenon. He maintains that the only satisfactory theory which can be advanced on the subject is that which connects the phenomenon with the principle of the interference of light. He illustrates the latter principle by the well-known experiment, in which two rays of light emanating in different directions from a luminous point, are made to converge again by being reflected from the surfaces of two mirrors, and to combine together, or to destroy each other, according to the conditions of the experiment. If the light from which the rays issue be homogeneous, and if the routes severally traversed by them be made to *differ in length* by gradually displacing one of the mirrors, the point where they meet after reflexion will, in some positions of the movable mirror, exhibit a very vivid light, while in other intermediate positions it will appear *quite black.* The positions of the movable mirror, corresponding to which the two rays thus alternately conspire together, or destroy each other, will vary with the colour of the spectrum employed in the experiment. It results from this important fact, that when rays of white light emanate from the luminous point, they will exhibit at their point of concourse after reflexion a succession of prismatic colours, depending in each case on the position of the movable mirror.

It is found that similar effects may be produced if, instead of causing the routes of the two rays to differ in length, the *refrangibility* of the media through which they pass be subjected to a similar variation.

It is upon these two facts that M. Arago has established his theory of scintillation.

In the case of telescopic observations, he supposes that the rays of light which enter the telescope at opposite extremities of a diameter of the object-glass may have traversed strata of the upper regions of the atmosphere, which, either from variations of density or temperature, or from hygrometric causes, may possess different refractive powers. It might happen from this cause, that the red rays at the one extremity of the diameter might totally destroy

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those at the opposite extremity, and that the focus might pass from the normal colour of white to that of *green*, the complimentary colour of red. In the next instant the green might be totally destroyed, and the colour at the focus would, consequently, be red; and similar effects might manifestly be produced each successive instant, by the destruction now of one colour and now of another colour of the spectrum.

Generally, the rays will only *partially* destroy each other by their interference; in which case the light will still be coloured at the focus, although less intensely than if the destruction had been complete.

M. Arago had already established by experiment, that if even the twentieth part of a pencil of light were extinguished by the interference of any of the homogeneous rays, the light at the focus would appear *sensibly* coloured. It would, therefore, be sufficient that the strata of the atmosphere should, by reason of their unequal refrangibility, affect intermittently, and in a suitable degree, the twentieth part of the rays which the surface of a lens embraces in order that the focal point should acquire in succession the different prismatic colours. "Now," says M. Arago, "if we take into consideration the great length of the route traversed by the light from the superior limits of the atmosphere to the object-glass of the telescope; if we reflect, moreover, on the small difference of refrangibility which suffices to occasion the passage of two rays from the state of accord to that of destruction, on the effect of winds, however moderate, bringing incessantly new atmospheric strata before the telescope, it cannot excite any surprise that in observing *Sirius*, a star sufficiently low in our latitudes, as many as thirty changes of colour in a second have been noted." Having thus explained, by the principle of the interference of light, the twinkling of the stars in telescopes, M. Arago finds no difficulty in applying the same explanation to observations with the naked eye.* He then proceeds to show how the twinkling of the planets may be accounted for by the same principle, and he concludes the exposition of his views on this interesting subject by suggesting three different modes of measuring the scintillation of a star. We shall confine ourselves to a brief notice of the first of these *scintillomètres*, as he terms them, which is unquestionably the most ingenious in its conception, and the most conclusive as regards the character of its results. It depends on an experiment, which is originally due to M. Arago himself, and which he first gave an account of in the year 1824.† If a diaphragm be placed before the object-glass of a telescope, so as to allow the light to pass through a circular aperture, and if a

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* M. Arago has mainly explained the phenomenon of twinkling, whether as discernible in telescopes or as visible to the naked eye, by the unequal refrangibility of the media traversed by the rays of light which enter the object-glass of the telescope or the eye of the observer; but he has also endeavoured to show that some difference must exist in the *lengths* of the routes traversed by the rays, which would be capable in some degree of accounting for the phenomenon.

† *Annales de Chimie et de Physique*, tome xxvi. p. 431.

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star be observed with the telescope when the eye-piece is in the position of distinct vision, the image of the star will resemble a vacillating disc of light surrounded by alternate dark and bright rings. If the eye-piece be now gradually pushed in, there is a second position, in which the luminous disk in the centre will be replaced by a *black hole* surrounded by alternate bright and dark rings. By continuing to push the eye-piece towards the focus a third position will be found, in which the image will resemble that observed in the first instance; and thus a constant recurrence will take place as the eye-piece is pushed forward, the image alternating between a *luminous centre* surrounded by *dark* and bright rings, and a *central dark hole* surrounded by *bright* and dark rings. Now, to determine the second position of the eye-piece, viz. that in which the image of the star exhibits a black hole in its centre, instead of observing the star directly, the eye-piece may be placed exactly midway between the first and third positions. If the telescope be now directed to a star which twinkles, the phenomenon will manifest itself in a succession of accidental reappearances of a luminous point in the dark hole, *and these reappearances will be more numerous as the twinkling is stronger.* At the request of M. Arago, a series of observations of this kind were made by MM. Goujon and C. Matthieu. The following selection will serve as an illustration of them :—

Stars.	Height above the Horizon.	Number of Apparitions in Five Minutes.
	Jan. 14, 1851.	
Sirius	20°	40
Rigel	31°	17
Aldebaran	57°	13
Capella	81°	8
	Jan. 22, 1851.	
Sirius	24°	28
Procyon	46°	20
α Orionis	48°	15
Pollux	69°	12

M. Arago had concluded from theoretical considerations, that if the eye-piece were shifted from the second position to some position intermediate between the second and third, the apparitions of the luminous point would be more frequent than in the first instance. The results of actual observations afforded a complete confirmation of his conclusion.

Having fully expounded his own view of the origin of twinkling, M. Arago next examines the various theories advanced by preceding writers on the subject, and points out their inadequacy in every case to account for the phenomena.

M. Arago states that although he feels convinced that, in connecting the phenomenon of scintillation with the principle of interferences, he has viewed the subject in its proper aspect, still he is

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far from being of opinion that nothing further remains to be done. "For example," says he, "no one of my acquaintance has connected in an entirely satisfactory manner, and even to their numerical values, the planetary disks which the stars acquire, and the rings which surround them, with the theory of interferences." He adds, that he had been informed that M. Schwerd, a geometer of Germany, had succeeded in this research; but he was told at the same time that, according to the calculations of M. Schwerd, which besides were applied exclusively to simple lenses not achromatic, the diameters of the planets when seen in a telescope with a reduced aperture ought to appear enlarged like the stars, a result entirely contradicted by observation.*

Exposé historique des Travaux exécutés jusqu'à la fin de l'année 1851, *pour la Mesure de l'Arc du Méridien entre Fuglenæs,* 70° 40′, *et Ismäil,* 45° 20′. *Publié au Nom de l'Académie Impériale des Sciences de St. Pétersbourg, par W. Struve, Directeur de l'Observatoire Central de Russie. Suivi de Deux Rapports de M. G. Lindhagen, Astronome de l'Observatoire central sur l'Expédition de Finmarken, faites par Ordre du Gouvernement Norvégien en* 1850; *et sur les Opérations de Lapponie, exécutées en* 1851, *sous les Auspices de l'Académie Royale des Sciences de Stockholm.* 4to. pp. 44. St. Pétersbourg, 1852.

In this Report M. Struve gives a brief history of the operations connected with the measurement of the Russo-Scandinavian arc of the Meridian, which has now attained the colossal extent of 25° 20′. This great undertaking was first commenced in Russia in the year 1816, and was finally brought to a close in 1851, the labours of its execution having, consequently, embraced a period of thirty-seven years.

As has happened in some other similar instances, the measurement of this arc was not an independent project undertaken with a view to the advancement of physical science, but was suggested by the operations connected with the trigonometrical survey of a portion of the Russian empire. In 1816, M. Struve and General Tenner were charged, the one with the trigonometrical survey of Livonia and the other with that of Lithuania; and it occurred to both geometers to profit by their labours in measuring an arc of the meridian in their respective provinces.

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* In the *Cambridge Philosophical Transactions*, vol. v. p. 283 *et seq.*, Mr. Airy, proceeding upon the principles of the undulatory theory of light, has investigated the diffraction produced by an object-glass having a reduced aperture of a circular form, and has calculated the numerical values of the diameters of the spurious disks of the stars and of the alternate dark and bright rings surrounding them. The results were found to present a satisfactory agreement with Fraunhofer's measures.—EDITOR.